# Acoustic Seaglider™ for Beaked Whale Detection

Neil M. Bogue
Applied Physics Laboratory
University of Washington
Box 355640
Seattle WA 98195-5640
phone: (206) 221-7687 fax: (206) 543-6785 email: bogue@apl.washington.edu

James C. Luby, Ph.D.
Applied Physics Laboratory
University of Washington
Box 355640
Seattle WA 98195-5640
phone: (206) 543-6854 fax: (206) 543-6785 email: jcl@apl.washington.edu

Award Number: N00014-08-1-0309
http://www.apl.washington.edu

## LONG-TERM GOALS

This effort exists within a group dedicated to the use of autonomous underwater vehicles, and buoyancy-driven gliders in particular, to support Navy missions. The group generally uses the Seaglider™, developed at the Applied Physics Laboratory of the University of Washington (APL-UW), and develops or adapts instruments and glider behavior to support specific mission requirements. This group is informally called the Applied Seaglider™ Group, whose acronym, ASG, is also used to describe the Applied Seaglider™itself.

This report describes our efforts as part of the ONR Passive Autonomous Acoustic Monitoring (PAAM) program. The long-term goals of the PAAM program were as follows:

- Perform persistent and autonomous passive acoustic monitoring of a 500-1000 square nautical mile Navy exercise area for presence of marine mammals.
- Monitor for three weeks prior to, three weeks during, and three weeks after a typical exercise.
- Detect, classify and localize (DCL) vocalizing marine mammals.
- Provide actionable information in a timely manner to the officer in tactical command to support marine mammal mitigation efforts.

Over the past year, the long-term goals of the ONR PAAM program have changed somewhat, to concentrate on the DCL mission in support of monitoring of marine mammals, particularly in active Navy operating areas.

# Report Documentation Page

*Form Approved*
*OMB No. 0704-0188*

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

| | | |
|---|---|---|
| 1. REPORT DATE<br>**30 SEP 2011** | 2. REPORT TYPE | 3. DATES COVERED<br>**00-00-2011 to 00-00-2011** |
| 4. TITLE AND SUBTITLE<br>**Acoustic Seaglider for Beaked Whale Detection** | | 5a. CONTRACT NUMBER |
| | | 5b. GRANT NUMBER |
| | | 5c. PROGRAM ELEMENT NUMBER |
| 6. AUTHOR(S) | | 5d. PROJECT NUMBER |
| | | 5e. TASK NUMBER |
| | | 5f. WORK UNIT NUMBER |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>**University of Washington,Applied Physics Laboratory,1013 NE 40th St,Seattle,WA,98105** | | 8. PERFORMING ORGANIZATION REPORT NUMBER |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | | 10. SPONSOR/MONITOR’S ACRONYM(S) |
| | | 11. SPONSOR/MONITOR’S REPORT NUMBER(S) |
| 12. DISTRIBUTION/AVAILABILITY STATEMENT<br>**Approved for public release; distribution unlimited** | | |
| 13. SUPPLEMENTARY NOTES | | |
| 14. ABSTRACT | | |
| 15. SUBJECT TERMS | | |

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT<br>**unclassified** | b. ABSTRACT<br>**unclassified** | c. THIS PAGE<br>**unclassified** | **Same as Report (SAR)** | **9** | |

**Standard Form 298 (Rev. 8-98)**
Prescribed by ANSI Std Z39-18

## OBJECTIVES

The primary objective is to build a passive acoustic detection and recording system for the Applied Seaglider™, with particular attention to the automated detection and classification of beaked whale vocalizations, and to quantify the system's performance with respect to the goals of the ONR PAAM program outlined above.

## APPROACH

We have chosen to focus on automated detection, classification, and recording of beaked whale vocalizations. Beaked whales vocalize at depths greater then 200m and use frequencies above 25kHz, as described by Zimmer *et al.* [**2008**], Johnson *et al.* [**2004**], and Zimmer *et al.* [**2005**]. The described characteristics are a good match with the ASG's depth range and physical dimensions.

Our approach has been as follows:

- Design and build a new acoustic detection and recording system with sufficient sampling rates, processing power, and storage capacity to enable ASG as an effective platform for beaked whale detection and recording.
- Collaborate with Drs. David Mellinger and Holger Klinck at Oregon State University (OSU) on beaked whale detection and classification algorithms.
- Conduct a series of bench and in-water tests to characterize system performance (FY2009).
- Deploy locally in the presence of killer whales (*Orcinus orca*) as a proxy for beaked whales (FY2009).
- Deploy off Kona (west) coast of island of Hawai'i on beaked whale survey missions (FY2010).
- Deploy on instrumented Navy ranges (AUTEC, FY2010 and SCORE, FY2011) in the presence of beaked whales to quantify detection performance.

Key participants at APL-UW, in addition to the Principal Investigators shown above, were Bill Jump (hardware and system design engineer), Geoff Shilling (software engineer), Trina Litchendorf (ASG Lab), Angie Wood (ASG Lab), and Paul St. Laurent (ASG Lab). Drs. Mellinger and Klinck at OSU have provided detection algorithms and performed analysis of detector performance.

## WORK COMPLETED

This report's subject award, N00014-08-1-0309, expired on 30JUN2011. The award was granted a no-cost extension to that date to allow participation in an experiment at the U.S. Navy SCORE range in Southern California. Hence this annual report only covers work done between 1OCT2010 and the award expiration on 30JUN2011. The final report for N00014-08-1-0309 will summarize the accomplishments of the entire project, and is submitted separately. Subsequent work on the Seaglider™/PAAM program was done under ONR award N00014-10-1-0515, and is reported separately.

One major field deployment was done during FY2011, which completed the field test portion of the initial ONR PAAM program.   Details are provided below.

- SCORE, Southern California Offshore Range, San Clemente Is., CA

  4JAN2011 – 7JAN2011

  Seaglider™ S/N 178: 30 dives, 19 to 1km depth, 56.2 hours acoustic data (46.7GB)

  Seaglider™ S/N 179: 30 dives, 19 to 1km depth, 53.5 hours acoustic data (44.5 GB)

  Sample (digitization) rate:  ~194kHz

In preparation for these deployments, several hardware modifications were completed.  These included the ability to utilize both the 10V and 24V Seaglider™ battery packs to power the PAAM system, and the ability to host multiple USB memory sticks, mounted sequentially.  These modifications significantly enhanced the endurance of the Seaglider™ PAAM system; the former addressed battery limitations, the latter addressed data storage limitations.

Significant software upgrades were completed, including the installation of a refined detection algorithm (ERMA) developed by Drs. Mellinger and Klinck at OSU, and described in Klinck and Mellinger [**2011**].  Initial work was performed to characterize and begin the implementation of a classifier for odontocete echolocation clicks developed by Roch, Klinck *et al.* [**2011**].  In addition, Karolin Klinck at OSU completed the detailed analysis of the detection data from the June 2010 AUTEC sea test.

**RESULTS**

Surfacing positions for the two Seagliders™ deployed on the SCORE range on 4JAN2011 are shown in Figure 1.  Both Seagliders™ were launched at the southeast end of a track line suggested by Dave Moretti of NUWC-Newport, based on his experience operating the Navy's Marine Mammal Monitoring on Ranges (M3R) system on the SCORE instrumented range. No beaked whale detections were made by the Seagliders™during the three-day deployment.  The M3R system also showed no beaked whale detections on hydrophones within acoustic range of the Seagliders™ in the same time period.  So while it was perhaps bad luck that the Seagliders™ did not detect any beaked whales on this deployment, it is encouraging that the negative result is consistent with the M3R results in the same area at the same time.

Vocalizations of other species of marine mammals were recorded during the deployment, however. An example is shown in Figure 2, a Long-Term Spectral Average from Seaglider™S/N 178's dive 12 on 6JAN2011.  This result is included to demonstrate the utility of the Seaglider™/PAAM system to record and resolve a variety of marine mammal vocalizations over a broad frequency band.

Drs. Mellinger and Klinck at OSU, along with K. Klinck, completed their analysis of the June, 2010 AUTEC deployments.  Their annual report will present their results, but a couple results are worth mentioning here, as they provide some system-level performance characterizations.  Recall that the 2010 AUTEC deployment consisted of two Seagliders™, one of which held station around the center of the AUTEC W1 array, while the other performed E-W transects across the range at the same latitude.

The performance of the Seaglider™ERMA detector was compared with the M3R detections coincident in space and time. Results are shown in Table 1 below.

***Table 1. Detector comparison from AUTEC, June 2010 deployment of two Seagliders™, courtesy of D. Mellinger, OSU.***

| Glider operation | BW encounters | ERMA detections | M3R detections | ERMA false detections | M3R false detections |
|---|---|---|---|---|---|
| stationary | 11 | 11 | 10 | 2 | 0 |
| transect | 12 | 12 | 8 | 1 | 0 |
| | | | | | |
| **Total** | **23** | **23 (100%)** | **18 (78%)** | **3** | **0** |

The ERMA detector did not miss any of the Seaglider™'s beaked whale encounters, but had a few false detections. The M3R system missed a few beaked whale encounters, but had no false detections. This may be because the M3R system is tuned as a ground-truth system, with a premium on low false-alarm rate, while the ERMA detector was tuned to not miss detections.

The Seaglider™/PAAM system detection range was approximated by measuring the horizontal distance between a Seaglider™ when it had a beaked whale detection, and the nearest AUTEC hydrophone with a beaked whale detection within five minutes. Note that ranges calculated in this way are not between the Seaglider™ and the beaked whale. Results of this analysis are presented in Figure 3. Detection distances of greater than six kilometers are probably coincidence, since the ocean's absorption of acoustic energy at the frequencies of the beaked whale clicks precludes detections at greater than about six kilometers. The results from the station-keeping Seaglider™ are probably more reliable, since there were longer beaked whale encounters, and the horizontal spacing of the W1 hydrophone array means there were more hydrophones near that Seaglider™ at all times.

These results suggest that the Seaglider™/PAAM system has a detection range for on-axis beaked whale clicks of up to 4km in the AUTEC environment.

Finally, a note on persistence. Under the following assumptions, the persistence of the Seaglider™/PAAM system is given in Table 2 below.

- 10V Capacity 3.7MJ, 24V Capacity 12.3MJ, both available to PAAM
- 9x64GB SD cards, 2x256GB USB sticks = 1088GB total storage
- 1000m dives, 4.75hrs, normal dive profiles (speed) and motor moves
- 194162 samples/s x 2 bytes/sample = 388324 bytes/s

***Table 2. Seaglider™/PAAM persistence in two 1000m dive sampling duty-cycles: nearly always on (detect below 5m) and on about half the time (detect below 500m). The gray shaded areas are energy constraints; the unshaded areas are data storage contstraints. The red numbers are the limits, in days.***

| **Detect_below depth** | **5m** | **500m** |
|---|---|---|
| 10V per dive | 18.4kJ | 17.6kJ |
| 24V per dive | 66.5kJ | 63.9kJ |
| Number of dives | 386 | 403 |
| Number of days | 77 | ***81*** |
| Storage per dive | 3.74GB | 1.83GB |
| Number of dives (to 90%) | 262 | 535 |
| Number of days | ***52*** | 107 |

The results are that under the assumptions given above, in a nearly always on configuration, the present Seaglider™/PAAM system can operate for just over seven weeks. In a 50% duty-cycle configuration, the system can operate for over eleven weeks. Total mission time could be longer if the acoustic recording/detection system was turned off during transits.

## IMPACT/APPLICATIONS

The Seaglider™/PAAM detection and recording system has achieved an initial operational capability. It has shown to be an effective tool for detecting beaked whale echolocation clicks, and relaying those detections ashore, with a reasonable amount of supporting data, in near real time. The Seaglider™/PAAM system can be used in a variety of ways: as a bell-ringer detection system, as a monitoring system, and as a survey tool. Its persistence and ability to make long transits to a survey area may be useful in remote operating areas.

The Seaglider™/PAAM system has the frequency range, computational power and flexibility, and persistence to be capable of a wide range of passive acoustic detection and recording missions. It is especially suitable for higher-frequency applications, where hydrophones can be small and large acoustic aperture is not required. The multi-channel electronics and sophisticated computational capability make integrating lower-frequency systems feasible.

## RELATED PROJECTS

There are many related projects to use passive acoustics to detect, classify, and monitor marine mammals; some are funded as part of ONR's broader PAAM program, some are supported elsewhere.

Dr. David Mellinger at OSU is directly funded by ONR under the PAAM program to provide beaked whale detection and classification algorithms. His annual report will cover these contributions in more detail.

**REFERENCES**

Baird, R. W., Webster, D. L., McSweeney, D. J., Ligon, A. D., Schorr, G. S., and Barlow, J. [**2006**]. "Diving behaviour of Cuvier's (*Ziphius cavirostris*) and Blainville's (*Mesoplodon densirostris*) beaked whales in Hawai'i", Can. J. Zool. **84**, 1120-1128.

Johnson, M., Madsen, P. T., Zimmer, W. M. X., Aguilar de Soto, N., and Tyack, P. L. [**2004**]. "Beaked whales echolocate on prey", Proc. R. Soc. London, Ser. B **271**, S383-S386.

Klinck, H., and Mellinger, D. K., [**2011**], "The energy ratio mapping algorithm: A tool to improve the energy-based detection of odontocete echolocation clicks", J. Acoust. Soc. Am., **129**(4), 1807-1812.

McSweeney, D. J., Baird, R. W., and Mahaffy, S. D. [**2007**]. "Site fidelity, associations, and movements of Cuvier's (*Ziphius cavirostris*) and Blainville's (*Mesoplodon densirostris*) beaked whales off the island of Hawai'i", Marine Mammal Science, **23**(3), 666-687.

Roch, M. A., Klinck, H., Baumann-Pickering, S., Mellinger, D. K., Qui, S., Soldevilla, M. S, and Hildebrand, J. A. [**2011**]. "Classification of echolocation clicks from odontocetes in the Southern California Bight", J. Acoustic. Soc. Am., **129**(1), 467-475.

Zimmer, W. M. X., Harwood, J., Tyack, P. L., Johnson, M. P., and Madsen, P. T. [**2008**]. "Passive acoustic detection of deep-diving beaked whales", J. Acoust. Soc. Am, **124**, 2823-2832.

Zimmer, W. M. X., Johnson, M. P., Madsen, P. T., and Tyack P. L. [**2005**]. "Echolocation clicks of free-ranging Cuvier's beaked whales (*Ziphius cavirostris*)", J. Acoust. Soc. Am., **117**, 3919-3927.

**FIGURES**

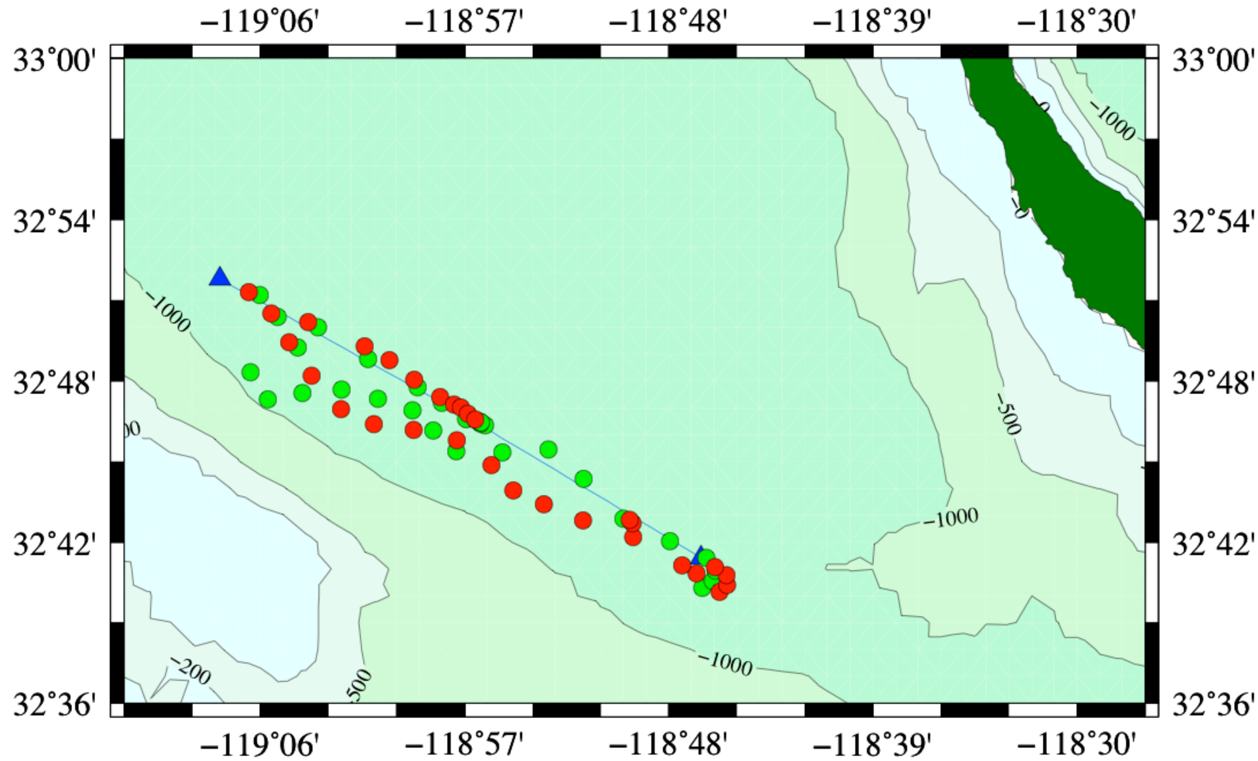


***Figure 1. Surfacing positions of Seaglider™ S/N 178 (green circles) and Seaglider™ S/N 179 (red circles) between 4-7JAN2011 on the SCORE range. The Seagliders™ were launched near the southeast waypoint (blue triangle), and flew toward the northwest waypoint (blue triangle), roughly following the 1500m isobath. Both Seagliders™ were recovered on 7JAN2011 about midway between the two waypoints as they were headed southeast.***

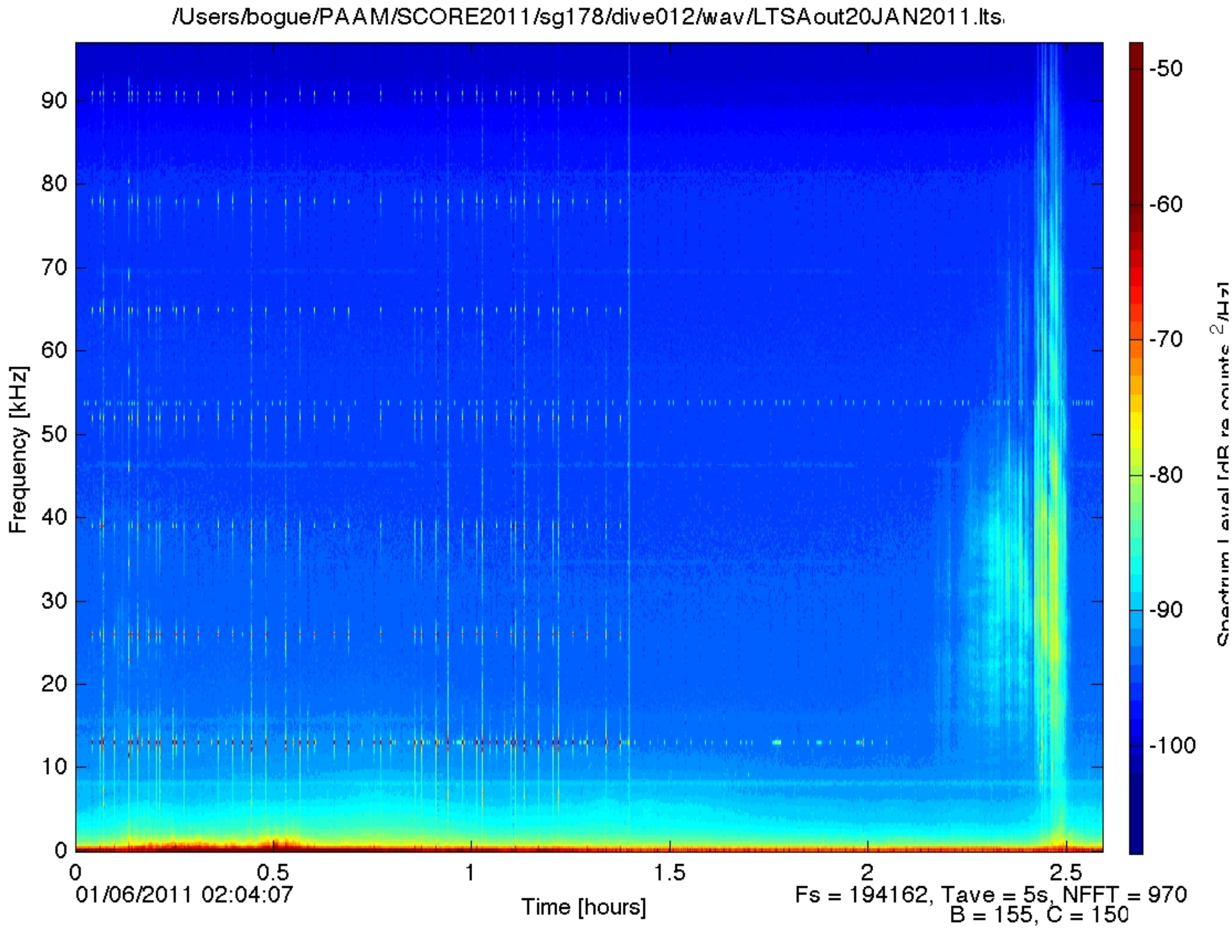


***Figure 2. Long-Term Spectral Average (LTSA) plot of acoustic data from Seaglider™ S/N 178 Dive 12, 6JAN2011, SCORE range. The pulses in the first half of the record, with fundamental frequency of about 13kHz and associated overtones are due to the Seaglider™'s own altimeter. Note the strong acoustic signal toward the end of the dive record, probably common dolphins. [LTSA produced using the Triton software package, courtesy of S. Wiggins, UCSD.]***

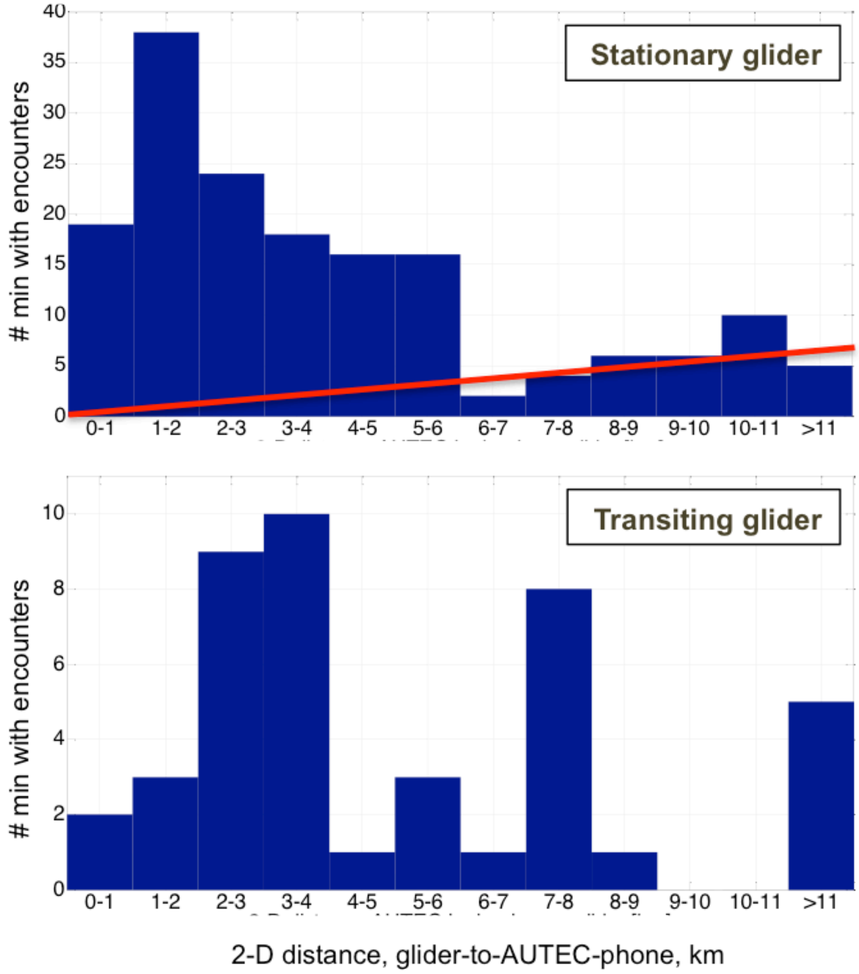


***Figure 3. Plots of distance from Seaglider™ to the nearest AUTEC hydrophone with a beaked whale detection within 5 minutes of each other. Note that this is not the distance from the Seaglider™ to the beaked whale. The vertical axis in each plot is the number of minutes with a beaked whale encounter. The stationary glider (SG178) held position near AUTEC array W1; the transiting glider (SG179) made E-W transects at the same latitude as the center of W1. Detections at hydrophones greater than 6km from the Seaglider are probably coincidental. [Figure and analysis courtesy of D. Mellinger, H. Klinck, K. Klinck, OSU***